Anatomical Information in Radiation Treatment Planning

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Abstract

We report on experience and insights gained from prototyping, for clinical radiation oncologists, a new access tool for the University of Washington Digital Anatomist information resources. This access tool is designed to integrate with a radiation therapy planning (RTP) system in use in a clinical setting. We hypothesize that the needs of practitioners in a clinical setting are different from the needs of students, the original targeted users of the Digital Anatomist system, but that a common knowledge resource can serve both. Our prototype was designed to help define those differences and study the feasibility of a full anatomic reference system that will support both clinical radiation therapy and all the existing educational applications.

INTRODUCTION

Understanding anatomy is essential for health care practitioners. Traditional anatomy knowledge resources such as printed atlases and plastic models are used as reference tools in clinical practice, but it is not yet known to what extent computer-based anatomy databases can be effective clinical support tools. Radiation therapy is a computer intensive process, and is a good area in which to investigate this. The University of Washington Digital Anatomist system[1] is an appropriate resource for building anatomy-based consultation tools. Two aspects of the UW Digital Anatomist system architecture make it uniquely powerful:

1. The data and knowledge are organized internally in a modular design, so it is easy to extend the content of the system.
2. The system is organized as a networked client-server system with well defined protocols, so it is possible to create new client front ends that are tailored to different uses.

We have built a prototype anatomic consultation tool as a clinical user agent for the UW Digital Anatomist system. We report our observations on what is needed to build a full anatomic reference system that will support clinical radiation therapy, and our experience with the design of prototype clinical tools.

REQUIREMENTS ANALYSIS

Radiation therapy is an important modality in the management of cancers; however, the tolerance of normal tissues is a dose-limiting factor which often results in the delivery of sub-tumoricidal doses. Incorporation of computed tomography (CT) and magnetic resonance imaging (MRI) into the radiotherapy planning process can help in designing radiation treatments that avoid critical structures while providing adequate coverage of the target. Dosimetrists and radiation oncologists use interactive graphic simulation systems, called radiation treatment planning (RTP) systems, to accomplish this. An example is Prism,[2] an RTP system developed at the University of Washington. The system is in routine clinical use at the UW for all external beam treatment planning, in addition to providing a base for several research projects.

An important step in the treatment planning process is the identification and contouring of all targets and normal structures on each CT/MRI slice. Figure 1 shows the drawing tool in the Prism system, used for drawing contours of normal and tumor anatomy on cross-sectional images.

Text-based anatomical references and consultation with diagnostic radiologists are often used in conjunction with the drawing facility of an RTP system, since it is often difficult to identify structures on a two-dimensional CT image, especially when the normal anatomy has been altered by the presence of infiltrating tumor. The complexity is increased when one considers alternate planes of orientation, i.e., coronal or sagittal. Thus, an integrated anatomical tool should be available to the planning staff via the planning software whenever it is required. If a consultation with a diagnostic radiologist is required, an on-line telemedicine consultation should also be possible, which implies that the tool should be designed to work in a network environment.

The Digital Anatomist was originally intended for educational purposes; in this setting, it was primar-

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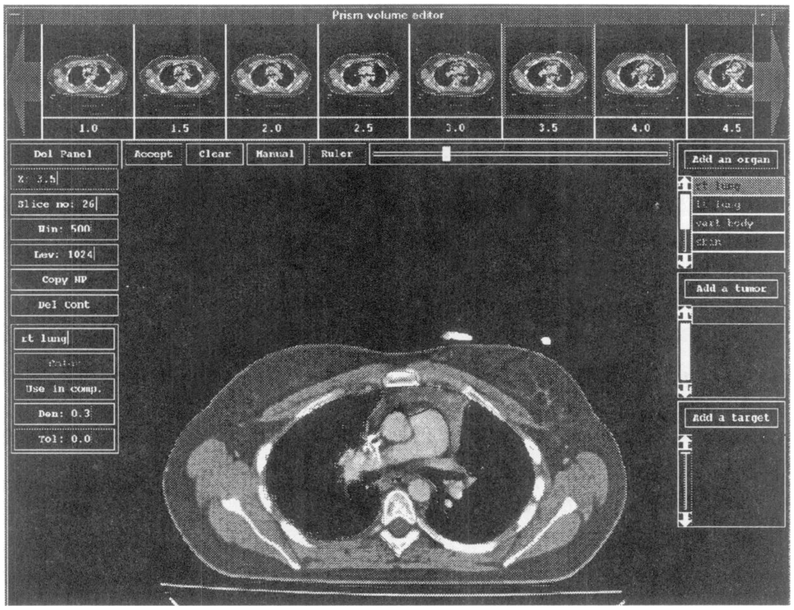

Figure 1: The Prism anatomy drawing panel showing a thorax cross section. Larger structures are easy to discern, but important smaller structures such as blood vessels, nerves and lymph nodes are impossible to see in these images.

ily used to identify or display predetermined structures. The RTP process potentially imposed different requirements on the anatomical database. Thus, a requirements analysis was performed prior to beginning work on our prototype. Our initial test cases involved the thoracic database. For example, Figure 1 shows a CT cross section of a patient with an anterior mediastinal lymphoma. Easy structures to identify include some of the great vessels, the lungs, vertebra, spinal cord and sternum. Difficult or radiolucent structures include important vessels, nerves and lymphatic organs. For malignant lymphoma, it is important to treat the lymph nodes and lymphatic vessels in the vicinity of the tumor. Thus, a basic requirement of our prototype is to be able to display the locales of requested organs, e.g., known lymphatic chains in the thorax. In addition, if one is unsure of a structure seen on a patient study, then the system should be able to identify the structure on a reference study. Figure 2 shows an atlas image labeled to answer such a query.

A really powerful system would allow for even more complex requests not possible with basic online or text references. For example, if one selects a particular structure, the system should be able to produce other structures directly upstream and downstream from it, e.g., it should show the trachea and the right and left main bronchi in relation to the carina. In addition, it should also show associated organs of different classes, i.e., appropriate vascular and lymphatic organs which supply or drain the carina. This is critical information to a radiation oncologist when considering potential local and regional routes of spread.

The prototype we built was a relatively thin user interface layer over the existing Digital Anatomist resources. We used it to further refine our requirements analysis; it was not intended to be a final solution to the clinical need. Therefore, as the prototype was revised, it was demonstrated to colleagues to assess its clinical applicability, as well as the feasibility of building a full clinical implementation.

PROTOTYPE DESIGN AND FUNCTION

The prototype clinical interface to the Digital Anatomist (DA) knowledge and image servers is a standalone program, used only for testing the ideas described above. However, we expected that we would follow this investigation with a clinical implementation. The clinical implementation would be most convenient as an integrated component of the Prism system, so we built the prototype with the same methods and tools as used in the Prism system. Therefore, like Prism, the DA clinical prototype is written in Common Lisp[3] and uses our locally written user interface toolkit, SLIK,[4] to provide a graphical environment for user interaction. The prototype runs on standard commerical workstations using the X window system,[5] and makes the network connections to the DA servers using standard TCP/IP socket library functions.

Our current prototype includes two interface panels, one that provides access to the DA Foundational

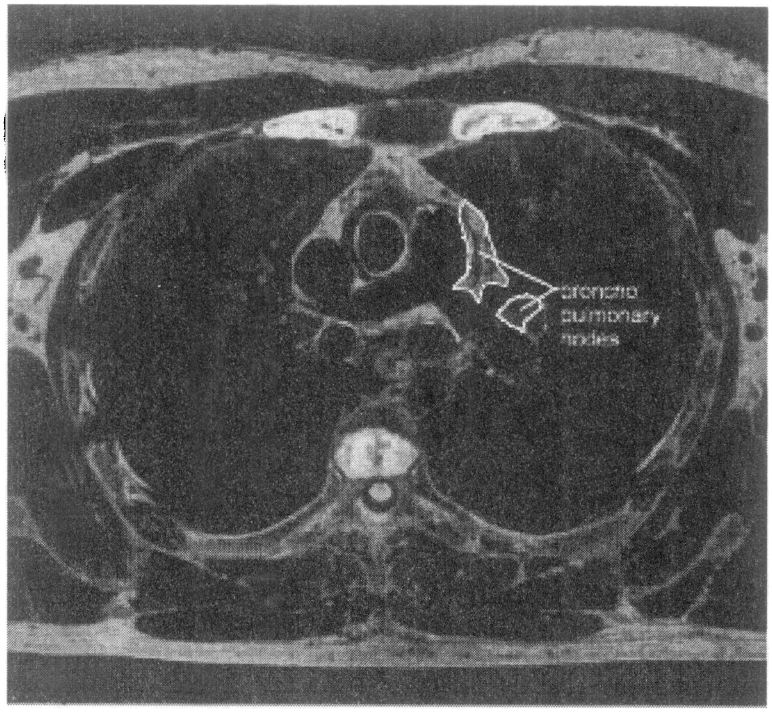

Figure 2: An image from the Digital Anatomist spatial database, along with a label indicating a structure that would otherwise be hard or impossible to find in the image itself.

Model Server, which is a symbolic description of the organization of the human body, and one that provides access to an annotated image database, the DA Annotated Image Server.[1]

The Terminology Panel

Symbolic information includes: anatomic terminology, definitions, glossaries, and semantic relationships. The Digital Anatomist Foundational Model expresses symbolic knowledge through anatomical relationship "hierarchies", forming a semantic network.[6] An example relationship is that the tracheobronchial and paratracheal lymph nodes, the left recurrent laryngeal nerve, and the thoracic duct are all represented as *part of* the mediastinum. The availability of this symbolic information makes powerful, intelligent searches possible. For example, a 3D reconstruction of a composite structure could be created dynamically by finding all of the atomic structures which are a part of it and rendering them one by one.[7]

The terminology panel is composed of a function menu, a term box, a hierarchy menu, a query display, a query button, a result display, and an exit button. These components provide an easy way for a user to form any of a large number of queries of the knowledge base contained in the Foundational Model Server's semantic network.

With this prototype, we wanted to lay the foundation for intelligent search by connecting to the Foundational Model Server, testing the functions provided by its application programming interface (API), and taking care of any other details that might be necessary for intelligent search. The resulting tool provides only a graphical user interface (GUI) as a thin veneer over the underlying API function calls. However, it opens up the door to intelligent searching, something not possible using the simple anatomy lists found in SNOMED[8] and UMLS.[9]

The Spatial Anatomy Panel

Whereas the terminology panel concentrates on symbolic information, the spatial anatomy panel focuses on spatial and image-based anatomical information. Spatial anatomic data in the Digital Anatomist are organized into a set of "atlases" which represent major body parts. For each atlas, a wide variety of annotated anatomical images are available: X-ray, CT, MRI, cryosections, illustrations, and 3D reconstructions.

Clinical anatomy reference books often help the dosimetrist or radiation oncologist by answering questions like "What" or "where is this?". In the former case, in which the user sees a structure in the patient scan which cannot be easily identified, he will search the book for an image of normal anatomy which shows the same area of the body as the scan and then mentally correlate the structures visible in the patient scan with the reference image to determine where the unknown structure lies in the reference image. Once the user determines this, he can look up the structure's name and/or its characteristics. In the latter case, the user is concerned about a particular structure which does not show up on the patient scan but which he knows is there. In this case he will look up the structure by name, find an image which shows the image in roughly the same plane as the scan, and once more mentally correlate visible structures on the scan with those in the reference to determine where in the scan the structure must reside.

The spatial anatomy panel provides corresponding on-line search functionality. It is composed of an atlas menu, a "find" box, a structures menu, a frame file menu, image windows, and an exit button. A snapshot of this panel is shown in Figure 3.

This interface enables the user to search for structures by providing a match string, to see what images are available for a given structure, and to display any image that contains information about a structure of interest.

DISCUSSION AND CONCLUSIONS

Evaluation of the Prototypes

Upon completion of the prototypes, the radiation oncologists evaluated the Digital Anatomist via test cases. One of them involved a malignant lymphoma of the anterior mediastinum. In this disease, it is imperative that all regional lymph nodes are irradiated. Figure 1 shows the CT slice as seen in the Prism anatomy panel, where structures are contoured; the bronchopulmonary nodes are not visible. However, the prototype was able to display the appropriate cadaver image with the requested structure outlined and labeled (Figure 2).

The prototype was also able to access the symbolic database, which maintains extensive intra- and inter-organ information; it can be queried with strings such as `is-a`, `part-of`, or `branch-of`. For example, a patient with a bronchogenic carcinoma arising in the carina requires irradiation of the adjacent trachea (upstream), as well as the main bronchi (downstream). Although one could just enter the term `bronchi` and have the prototype display them, the prototype was able to list the structures by virtue of their *relationships* to the carina. This type of information is vital in the treatment planning process.

The symbolic database is currently being expanded to include a model of spatial relationships such as adjacency (including direction). This makes possible even more intelligent responses to queries about relevant structures in relation to a specified tumor.

Additional Features

Other useful functions were identified for future implementation, including radiosensitivity data and the ability to fuse or morph anatomy from the reference studies to patient data.

The addition of radiosensitivity and radiobiological data to the database is an important consideration since the display of radiosensitive organs in the vicinity of the tumor can serve as a reminder to the dosimetrist. It is also useful in the comparison of plans with complex oblique irradiation geometry. The Prism system includes the ability to compute and display cumulative dose-volume histograms (DVH) which show the minimum volume of an organ receiving a certain dose. A calculation combining radiobiological data (from the Digital Anatomist database) with the DVH for an organ yields its normal tissue complication probability (NTCP), or the probability that the plan will result in certain sequelae. This can be used to compare the efficacy of 3D plans since it would be advantageous to choose the plan with the lowest probability of normal tissue injury.

Furthermore, an important function would be the ability to fuse the information contained in the database with a patient's diagnostic scan, i.e., it would be preferable to identify a structure on the patient's study rather than the reference case. This requires detailed coordinate spatial data from multiple reference cases. Also, since the contouring of normal structures is a laborious task, it may be advantageous to have the planning system automate a portion of the process. Ultimately, the usefulness of a reference source is limited by altered organ positioning due to tumor extension or normal variation. As well, the planning CT and MRI can each be in different planes of orientation than the reference image, thus making it difficult for the oncologist to extrapolate a structure's position from one study to another.

Technical Issues

We encountered very few technical difficulties in constructing the prototypes. The prototypes created to date allowed us to demonstrate the technical feasibility of our objective and gave us some insight into the form a full clinical tool might take. The next steps will be to refine the user interface and to add some content to the image database. For example, although the current Digital Anatomist database contains many segmented images, only a few of the images depict areas of the body relevant to radiation treatment planning. Because the DA's open architecture permits the expan-

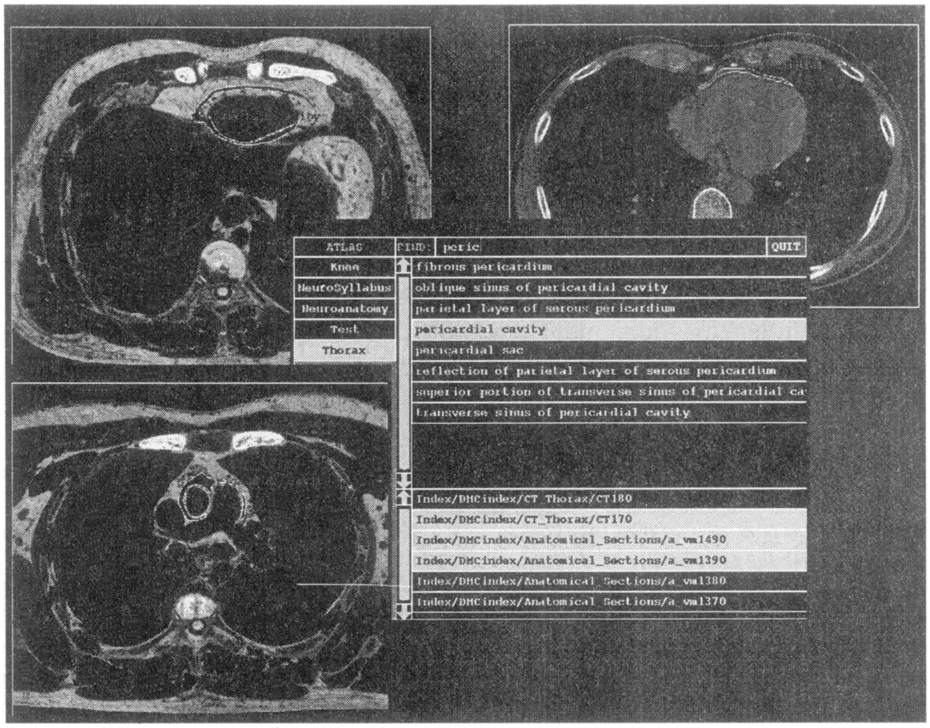

Figure 3: A screen snapshot of the spatial anatomy panel

sion of each database at any time, we plan to implement these additions in the future. This work should lead to a powerful tool that will increase the precision of radiation treatment.

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